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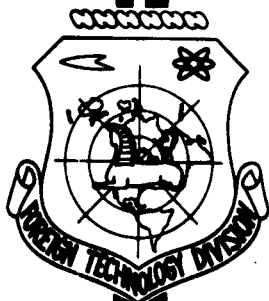
TRANSLATION

USE OF TRANSISTORS FOR CONVERTING
DIRECT CURRENT

By

Yu. K. Zakharov

FOREIGN TECHNOLOGY DIVISION



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USE OF TRANSISTORS FOR CONVERTING DIRECT CURRENT

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USE OF TRANSISTORS FOR CONVERTING DIRECT CURRENT

by

Yu. V. Zakharov

In the article there are presented experimental material on the use of transistors for converting direct current.

At the present time wide use is made of the conversion of DC on transistors. This is explained by the fact that such converters have a substantial advantage over vibration and electrical-machine converters. Among these advantages one can cite:

- a) higher dependability in operation and a longer period of service due to the absence of mechanical contacts and moving parts;
- b) possibility of effecting conversion to frequencies of from some hundreds of cps up to five to ten thousand cps, which makes it possible to decrease sharply the dimensions and weight of the transformers and smoothing filters;
- c) in most systems higher efficiency (of the order of 70 to 90%);
- d) higher stability as against the action of climatic and mechanical factors.

At the present time there have been developed converters of DC with a current of some units of watts up to some hundreds of watts onto an output voltage of from 1.5 to 27 v. Besides, on the transistors one can accomplish the conversion of AC with very high efficiency.

In the conversion of DC one uses only flat triodes which have little output resistance in the open system (in saturation) and great resistance in the closed system and which allow for commutation of quite strong currents. These requirements are satisfied by triodes P3, P4, P201--P203, and the newly developed powerful triodes of the type P207--P210 put out by the national industry.

Experience in the development and experimental researches show that dependable operation of converters can be assured only with a correct of working with the triodes.

It is necessary that the temperature of the monocrystal of germanium as well as the reverse voltage applied to the electron-hole-type transits does not exceed the permissible limit values.

The temperature of the triode is ^{determined} by the temperature of the surrounding medium, the power distributable in the triode, and the effectiveness of its cooling.

Taking into consideration that the apparatus can work at a given level of temperature of the surrounding air, and that the permissible limit of temperature for the crystal of germanium is 80 to 90°C one can determine the permissible overheating.

The power dissipatable in the triodes in working in the system of a converter of DC is made up of the following components:

losses brought about by the output resistance of the triode in the system of saturation, which do not exceed 0.5 to 0.6 v for triodes P4;

losses occasioned by the inertia of the resorption by the current carriers in the triode and the nonrectangular form of the curve of the voltage on the windings of the transformer, called junction losses which depend on the frequency properties of the triode and the system of its connecting up, as well as on the method of accomplishing the feedback (for the converters with autexcitation);

losses conditioned on the current through the collector transit of the triode during the period of operation when it is closed. These losses depend on the value of the zero current of the collector of the triode and the feed voltage, and in triodes of the type P4 they may amount to 0.3 to 0.5 v;

losses from the current through ^{the} base of the triode, not going higher than 0.1 v.

The total power dissolvable in the triode in operating in the circuit of a converter can amount to 1 or 2 wt, which leads to the need for applying additional heat drainage in the form of copper or dural plates and cylindrical radiators. In a number of instances of conducting away heat there is used the frame of the unit. In this case to insulate the triodes from the frame there is used mica of a thickness of 0.1 to 0.05 mm or other insulating film materials.

In connection with the fact that the triode should operate in a very broad range of temperature experiments were conducted with the basic electrical parameters of the triodes of the type P4 with change of temperature of the frame of from -50 to $+90^{\circ}\text{C}$.

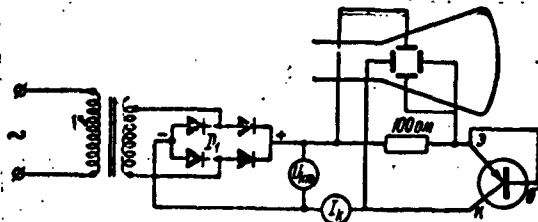


Fig. 1. Diagram showing the principles of the unit for measuring the punch-through voltage of the triode

The coefficient of amplification of the current for the system of a general emitter on the raising of the temperature from -50 to $+20^{\circ}\text{C}$ drops by 20 to 30%, and on further raising the tem-

perature to $+90^{\circ}\text{C}$ it drops insignificantly (by 5 to 7%).

In agreement with the lowering of the coefficient of amplification with the raising of the temperature there is an increase in the dropping of the voltage on the triode in the system of saturation.

The zero current of the collector junction of the triode on the raising of the temperature increases sharply reaching at a temperature of $+80$ to $+90^{\circ}\text{C}$ on the average 5 to 10 ma, while the factor of the change in the zero

current drops with the increase in the voltage applied to the collector junction.

For example, the factor of increase in the zero current of the collector with a voltage of 50 v in the interval of temperature of $+20$ to $+90^{\circ}\text{C}$ does not exceed 3 to 5.

The powerful triodes put out at the present time of the type Ph, as practice has shown in their use, require additional checking for the limiting allowable collector voltage. The existing procedure of classification of triodes in accordance with reverse current does not enable one to assure high dependability in the functioning of triodes at voltages close to the limit of the permissible. In this connection recently there has been applied a procedure of classification by the puncture collector voltage in the scheme presented in Fig. 1.

The puncture voltage is determined with the aid of an oscillograph and a voltmeter in accordance with the sharp bend in the voltmeter characteristic of the collector junction (Fig. 2).

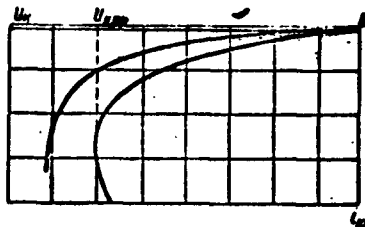


Fig. 2. Voltmeter characteristic of the collector junction of the triode

In the case of the application of the triodes in two-cycle circuits and for assuring stability of the functioning in parallel connecting it is feasible to introduce the classification of triodes by the

steepness of the junction characteristic S (dependence of $U_{BX} = f(I_K)$, which can be determined in accordance with the formula

$$S = \frac{I_{km}}{\sqrt{2}U_{BX} - U_n}$$

where I_{km} is the amplitude of the collector current of the triode,

U_{BX} is the voltage on the input of the triode (AC),

U_n is the threshold voltage $p - n$ of the junction, which for the existing

triodes can be taken to be of the order of 0.27 to 0.3 v.

For measuring the steepness of S one can use the circuit presented in Fig. 3 or the ordinary or the ordinary scheme for taking the statistical characteristics of the triodes.

One can show that the steepness of S is determined by the coefficient of the amplification b in the input resistance, which makes it possible to pick out by one parameter the triodes for the two-cycle system and for parallel connecting.

In this connection for all the triodes developed and put out at the present time it is feasible to introduce the classification by the steepness of the junction characteristic of the triode.

Let us consider the circuits of the converters of AC. The single-cycle circuits of the converters (Fig. 4) found application for the conversion of relative small powers (of the order of 2 to 4 w). However, as investigations

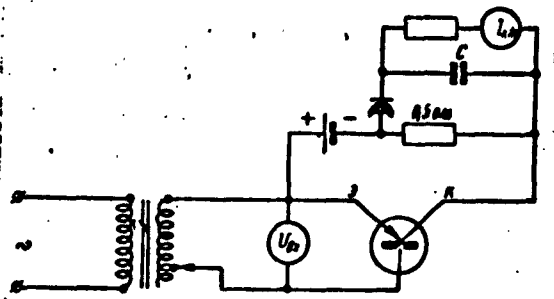


Fig. 3. Drawing showing the principle of the setup for measuring the steepness of the junction characteristic of the triode

have shown, they can be successfully used also for the conversion of considerably greater power.

In single-cycle circuits there are possible two methods of connecting the diode in the circuit of the secondary winding --

in the direct or reverse direction. In the direct connecting of the diode there is current in the secondary winding when the triode is closed. In the operation of converters with these methods of connecting the diode there is substantial difference.

Table

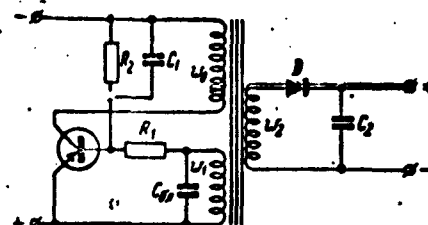
Input voltage, v	Efficiency, %	Power P_n , v, with diode closed	
		reverse	direct
2.4	60	1.7	3.5
4.8	70	3.8	6.6
6.0	70	4.6	9.2
12	80	9.4	18
24	80	12.5	25

In the circuit with the reverse connection of the diode the power transmitted to the load is determined by that magnetic energy which accumulates in the inductivity of the transformer in the course of time when the triode is open.

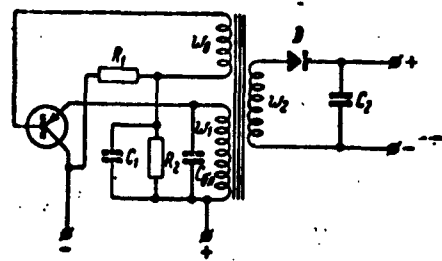
The pulse of the input current of the converter for such a circuit has a triangular form. The form of the pulse of the input current and the maximum value for the collector current permissible for a given type of triode determine that magnetic energy which accumulated in the inductivity.

In the circuit with the direct connection of the diode the current in the secondary winding flows during that period of time when the triode is open.

In this case the form of the pulse of the primary current will be nearly rectangular, as a result of which the power which may be converted with the aid of such a system will be twice as great as the power which can be converted with the aid of a circuit with reverse connection of the diode.



a)



b)

Fig. 4. Diagram showing principles of circuit of single-cycle converters of AC with different ways of connecting the triode:

a) with the common emitter, b) with the common collector

In the table there are presented the computed values of the power on the output of the converter (P_H) for the two schemes of connecting the diode while using one triode of the type $6A$ ($I_{km} = 2.5$ amp, $U_{pm} = 50$ v).

It is necessary to note that in the scheme with the direct connection of the diode for assuring a determined porosity of the pulse of the input current and limiting of the amount of the voltage on the windings of the transformer in the nonoperating part of the period there is used a blocking capacitance C_{GK} (Fig. 4).

One should also note that with low input voltages the single-cycle circuits enable one to make use of triodes more effectively than in the two-cycle circuits. This is explained by the fact that the triode can operate, both with the maximum collector current and with quite high collector voltage, independently of the amount of input voltage.

The widest application is being made at the present time of converters of DC assembled with the two-cycle circuits, both with self-excitation and with a master oscillator.

The two-cycle circuits enable one to accomplish the conversion with the highest efficiency (70 to 90%). In the two-cycle systems there is assured good use of the transformer, and its dimensions will be less than with the same power using the single-cycle system.

In Fig. 5 there are presented the most widely used schemes of converters of DC. In connection with the fact that in using systems with a common emitter (Fig. 5, a) ordinarily it is necessary to insulate the triodes and their radiators from the frame of the unit it is to the point to use circuits with a common collector (Fig. 5, b), or with a common emitter and united collectors (Fig. 5, c), which enable one to fasten the triodes directly to the frame of the unit, and, consequently, to assure the greatest effect-

iveness in their cooling. In their electrical characteristics the converters designed in accordance with the circuits in Fig. 5, b and c, practically do not differ from the converters designed in the system with a common emitter (Fig. 5, a).

Practical interest is afforded by the two-cycle system of converter with the connecting of the triodes on the scheme of a common base and joining of the collectors (Fig. 5, d). It is feasible to use the scheme being considered for master oscillators since it enables one to assure high dependability of the working of the triodes with raised feed voltage (27 to 30 v), high stability of the working parts, and sufficiently good rectangularity of the curve of voltage on the windings of the transformer.

Without dwelling on the principle of the operation we will touch some problems in the practical application of practical application of converters on the two cycle system. The most important problems in the development of converters of DC are: choice of the frequency of the current, the core of the transformer, and the mode of its operation, and the system of the working of the triodes and ways of connecting them.

The choice of the frequency is made with consideration for the minimum effect of radio interference, created by the converter, on the apparatus, and also with a view to obtaining the maximum efficiency and minimum weight of the converter.

In using converters in an apparatus of communication it is feasible to select the frequency either below 300 cps or higher than 2.0 kcps. One should note that with a frequency of two or three kcps the efficiency of the converters begins to go down noticeably as a result of the increase in the relative magnitude of the junction losses in triodes. At the present time there are ways projected for lowering the junction losses in the triodes by

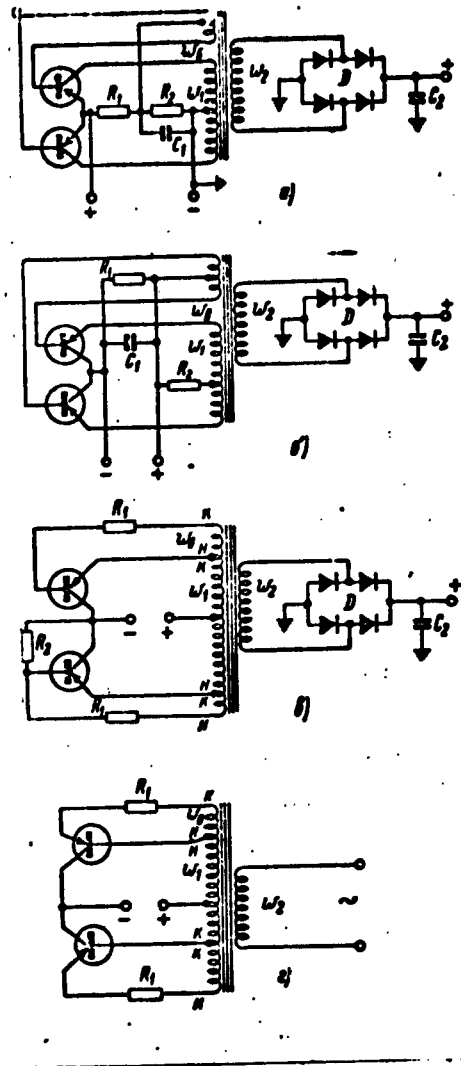
Fig. 5. Diagrams showing the principles of the circuits of the two-cycle converters of voltage with different methods of connecting the triodes:

a--with common emitter,

b--with common collector,

c--with common emitter and joined collectors,

d--with common base and joined collectors



connecting them on a scheme with a common base, and also through the use of the feedback on the current, which enables one to raise the working frequency above 2 to 3 kc/s while keeping the high efficiency (above 80%).

It is very important for obtaining high efficiency in a converter to choose correctly the system of working of the transformer. It is advantageous in transformers to use tape cores from steel KhVP of a thickness of 0.08 to 0.05 mm. It is very suitable as core material to use permalloy ma-

terials with a rectangular hysteresis loop. However, such materials find practical application only after industry has taken over seriously the production of cores with a rectangular hysteresis loop.

With frequencies of the order of 5 to 10 kcns one uses transformers with cores made of oxide of ferromagnetic material with initial penetration factor of the order of 2,000 to 3,000. It is most feasible to use manganese-zinc oxyfers (oxides of ferromagnetic material) which have considerable stability at temperatures of $+100$ to $+120^{\circ}\text{C}$.

As a result of the nonsinusoidal quality of the currents and the voltages in the converters during operation there arise radio disturbances in the spectrum up to 30 megahertz. The level of the voltages of the radio disturbances can reach tens and hundreds of thousands of microvolts. For suppressing the radio interference one uses U-shaped filters on the input of the converter. The inductivity of the choke of the filter selected is around 40 to 60 μH and the capacitance of the capacitors 4 μF (it is necessary to use paper capacitors).

For determining the performance of the converters during protracted working tests were made over a period of service of a series of DC converters with ambient temperature of the air $+20$ and $+50^{\circ}\text{C}$. The results of the tests showed that after that after 3,000 to 6,000 hours of continuous work the efficiency and the output power of the converters changed by 1 to 5%.

In connection with the advantages indicated above of the DC converters based on semiconductor triodes (transistors) it is profitable to continue the work for improvement of their characteristics in the direction of perfecting the circuits, raising the operating frequency, and the using of new small-dimensioned parts.

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